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Guidelines on the prevention of built-in moisture

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SUMMARY:

As a result of built-in-moisture, a number of buildings in Denmark were attacked by moulds even before the users moved in. Therefore, the Danish Building Regulations have since 2008 stipulated that building structures and materials must not, on moving in, have a moisture content that is liable to increase the risk of mould growth. In some cases, authorities can demand that this should be documented by a moisture specialist.

The paper describes a voluntary Danish guideline on how to comply with the requirements and the intentions in the Danish Building Regulations concerning the handling of moisture at each stage of the building process spanning from the proposal phase to delivery of the building and the 1-year and 5-year inspections. This includes categorising a specific building in a humidity risk class as the risk for moisture damages is related both to the expected exposure to moisture during the execution phase and the building's capacity to withstand moisture. It also specifies how moisture should be dealt with in the general quality assurance system of the building industry.

The Danish guideline is compared with similar guidelines and tools in other Nordic countries. The education of moisture specialists is emphasised and it is questioned whether a voluntary guideline will have the desired effect.

1. Introduction

Moisture in buildings often results in an unhealthy indoor climate. This has been known for a long time and many efforts have been made to avoid moisture after moving in. Moisture added to the building during the execution phase has been regarded as unavoidable and it was expected to dry out during the building's first year of use. In a number of cases in Denmark, the completed building was so wet - because of moisture added to the building during the execution phase - that part of the construction was attacked by moulds even before the inhabitants began using the building.

As a result, the Danish Building Regulations (DBR) have since 2008 stipulated that building structures and materials must not, on moving in, have a moisture content that is liable to increase the risk of mould growth (Danish Enterprise and Construction Authority 2008). In 2010, a guideline was introduced to help clients comply with requirements and the intentions outlined in DBR concerning how to deal with moisture at each stage of the building process (Møller 2010). This includes the categorisation of a specific building in a humidity risk class, as the risk of moisture damage is related both to the expected exposure to moisture during the execution phase and the building's susceptibility to moisture. It also specifies how moisture should be handled in the general quality assurance system of the building industry.

2. Moisture requirements in the Danish Building Regulations

A general requirement to construct buildings to prevent water, moisture and damp from causing damage has been part of DBR since 1972 (Ministry of Housing 1972). In 2008, three important requirements concerning control of the moisture content in building structures and materials were added (Danish Enterprise and Construction Authority 2008). The first one states that measures to counter weather conditions that are essential to the proper construction of a building must be taken during planning, design, tendering and execution. The functional requirement may, for example, be complied by:

- a. Avoiding materials and constructional solutions that are unduly moisture-sensitive
- b. Explicitly allocating time in the client's tendering plan and time schedule for all necessary drying out of building materials and structures
- c. The client carrying out a cost-benefit analysis of fully enveloping the building during execution. Further by prescribing total enveloping if it is financially viable, or where the tender documents specify particularly moisture-sensitive materials or constructional solutions
- d. The client providing shared facilities for storage of moisture-sensitive materials.

The second requirement states that:

- e. Building structures and materials should not, on moving in, have a moisture content that is liable to increase the risk of mould growth.

In both new buildings and renovation projects, this requirement minimises the risk of moving into overly damp buildings and the risk of mould growth.

Finally, in the administrative provisions it is stated that

- f. The building permit may impose requirements for the measurement or other types of documentation provided by a moisture specialist in order to verify compliance with requirement e) with respect to the critical moisture content of structures and materials.

This requirement highlights the need of specialists to document moisture conditions at execution.

3. Guideline for dealing with moisture in the execution phase

DBR does not describe how it is documented that these requirements are complied with. To a great extent, the client and the authorities are entrusted with interpreting the requirements in a specific case. Therefore, a guideline for dealing with moisture in the execution phase was prepared for the Danish Enterprise and Construction Authority (Møller 2010). For each step in the building process from the preliminary design phase to the 5-year inspection, the basic decisions are presented and it is suggested, what kind of documentation would be relevant, and how this should be implemented in the quality assurance system of the building industry.

The client defines the kind of competences of the moisture specialist and the amount of documentation that would be relevant in order to comply with requirement f). The moisture specialist does not have to be independent of the contractor. His tasks are described in (Aagaard et al. 2011) and it is emphasised that the requirements in DBR are minimum requirements and that the client may benefit by setting stricter requirements. Therefore the construction client needs guidance to decide

- when it is relevant to consult a moisture specialist
- what kind of competences should be asked for
- how the competences of the specialist should be documented, and
- what kind of requirements can be made to the work of the moisture specialist in the different phases of the construction project.

A number of fundamental decisions on materials and design are taken very early in the building process. Many discontinuities and penetrations will for example increase the risk of moisture entering both during execution and afterwards in the operating phase. From an early stage in the building process, the client must therefore consider if and when a moisture specialist is needed. It is recommended to categorise the building in the relevant humidity risk class (Section 3.2). By doing this, the actors in the building process have from the beginning an idea of whether moisture is expected to demand more than normal attention and can evaluate whether the project would benefit by a involving moisture specialist.

3.1 Documentation

For each stage in the building process, Møller (2010) suggest, what kind of moisture documentation would be relevant as listed in Table 1. The documentation should be part of the quality assurance system of the different companies that at some point or other are involved in the building process.

TABLE 1. List of moisture documentation referring to different stages in the building process.

Stages in the building process	Documentation of moisture conditions
Project proposal	A list of conditions subject to risk regarding moisture Description of precautions to respond to the risk
Project design	A moisture strategic plan including <ul style="list-style-type: none"> • Description of steps that call for special attention in the execution phase • Description of what precautions the project supervisor has taken • A control plan documenting conditions throughout the building process and working as a “warning lamp” • Description of remedies or actions to correct defects
Tender	Tender documents should include <ul style="list-style-type: none"> • Control plans, describing for each building element when and how to control moisture conditions • Description of how a random check of moisture conditions is to be documented
Execution	Moisture measurements and photos from delivery of the materials and elements to the closing of a construction, according to control plans. Measurement results are evaluated before materials are built-in and again before constructions are closed.
Delivery	Ensure that moisture conditions do not exceed the requirements and if they do, this should be added to the list of deficiencies. Ensure that the documentation report made by the moisture specialist is added to the documents delivered to the authorities if they have requested documentation of the moisture conditions.
1- and 5-year inspection	Control measurements to document whether the moisture conditions are satisfactory. If moisture problems are detected: Documentation of whether the problems are caused by inexpedient operation or defects that can be related to the project design or the execution.

The guideline accentuates the possibility of conducting a preliminary dialogue between the authorities and the client to ensure a higher quality of the completed building, to achieve a better economy during the building process, to reach a better understanding between client and authorities and to improve the quality of the application documents. Finally expectations to the documentation material can be adapted, including an assessment of the need for documentation of the moisture conditions.

3.2 Humidity risk classes

The risk of moisture problems arising during the execution of a building depends primarily on

- how great the moisture exposure is during execution
- how susceptible the building is to moisture.

By combining these two properties, it can be assessed in which humidity risk class a building belongs during execution. Based on this, the actors in the building process can evaluate what measures it would be relevant to take. The Danish guideline (Møller 2010) includes three humidity risk classes labelled 1, 2 and 3, as listed in Table 2.

TABLE 2. Humidity risk classes as a function of exposure to moisture during execution and the susceptibility of the building to moisture.

The susceptibility of the building to moisture	Exposure to moisture during execution		
	Low	Medium	High
Low	class 1	class 2	class 2
Medium	class 1	class 2	class 3
High	class 2	class 3	class 3

Whether the exposure to moisture during execution is low, medium or high depends on

- how wet the construction and assembly processes are, e.g. concrete cast in situ
- to what extent the construction and assembly processes take place without covering.

The susceptibility of a building to moisture is related to

- the ability of materials to absorb moisture
- the mould risk of a specific material
- the time available for drying.

It is highlighted that the combination of materials can be critical, e.g. the combination of moisture-sensitive materials like wood and plaster boards and materials with a high amount of moisture at execution like concrete cast in situ.

TABLE 3. Suggestions of how humidity risk classes can be utilised to determine the need for measures before and during execution. All measures must be documented.

	Risk class 1	Risk class 2	Risk class 3
Before execution	Comply with minimum requirements in DBR	Minimum requirements and: – Setting up a moisture strategy plan	Minimum requirements and: – Setting up a moisture strategy plan – Calculation or simulations if possible – Involve a moisture specialist
During execution	– Moisture measurements at critical times; as minimum before closing the building	– Continuous moisture measurements – Limited measurement programme – Assess specific potential moisture problems	– Continuous moisture measurements – Expanded measurement programme – Involve a moisture specialist

It is not a requirement to categorise a building or a part of a building in a specific humidity risk class before execution or to decide whether the risk class varies during execution. However, by introducing

humidity risk classes, the consulting engineer can make it quite clear to the client that he is taking a risk. The engineer can also demonstrate how the risk can be reduced and where special precautions are necessary, including the use of a moisture specialist, as described in Table 3.

4. Discussion

Moisture related problems in new buildings are well known not only in Denmark but e.g. in Sweden (Samuelsson & Wånggren 2002) and Norway (Mehus et al. 2004). The requirements in the building regulations for airtight buildings to ensure high energy performance as well as the use of moisture sensitive materials highlights the need to control the moisture content of building materials and components during the building process.

4.1 Moisture requirements in building regulations in other Nordic countries

Like in Denmark, the building regulations in Sweden and Norway include a general requirement to prevent moisture from causing damage (Boverket 2011; Ministry of Local Government and Regional Development 2010), e.g. the Norwegian one stating that ground water, surface water, precipitation, construction moisture and vapour must not enter and cause moisture damage, formation of mould or dry rot or hygienic problems.

Additionally, the Norwegian Building Regulations (NBR) states that materials and constructions must be sufficiently dry when they are built in or sealed to avoid problems with mould or dry rot (Ministry of Local Government and Regional Development 2010; Directorate for Building Quality 2011).

The Swedish Building Regulations (SBR) prescribes that the moisture condition of a building element may not exceed the critical moisture conditions (Boverket 2011). SBR even prescribes that the moisture conditions are to be calculated for a worst-case scenario. This is more descriptive than DBR, which does not specify how the critical moisture conditions are to be identified.

In Table 4 requirements in the Danish, Swedish and Norwegian Building Regulations and the existence of guidelines are compared with reference to prevention of built-in moisture.

TABLE 4. Moisture requirements in national building regulations in Denmark, Sweden and Norway and existence of guidelines for a moisture safe building process.

Requirement in national building regulations	Denmark	Sweden	Norway
To prevent moisture from causing damage	General	General	General
That materials and building elements may not exceed a critical moisture content ¹	Yes, at moving in	Yes	Yes, at building in
Documentation by moisture specialist	Yes	No	No
Formal requirements for moisture specialist	No	No	No
Moisture calculation as documentation	No	Yes	No
Guidelines	Voluntary	Voluntary	No
Education for moisture specialist	No ²	Exists, but not required	No
Critical moisture content	75 %RH	75%RH	20 weight-% ³

1): Comparable to the Danish requirement presented as e) in Section 2.

2) Post graduate education in building physics established.

3) Critical moisture content for wood.

Since 2008 DBR specifically requires that documentation concerning moisture conditions has to be elaborated by a moisture specialist, presented as requirement f) in Section 2. Neither NBR nor SBR includes a similar requirement. However, since 2009 requirement f) does not apply to detached single-family houses and terraced houses as it was decided to more or less skip the technical aspect of the processing of applications for buildings permits in Denmark for these types of buildings. They are labelled “constructions of limited complexity”. Although this highlights the client's responsibility to

comply with DBR, it can be questioned whether such a simplification is appropriate as no survey has been made to justify that detached single-family houses and terraced houses have less problems with moisture on moving in than other types of buildings. Actually, the most known cases in Denmark with critical moisture content on moving in are in terraced houses.

In Norway a similar transfer of responsibility of the technical contents from the authorities to the client took place in 1997 as the technical aspect of the processing of applications for building permits was radically diminished (Øyen et al. 2008). The volume of defects caused by moisture, and defects in general, related to the execution phase was reduced after the transfer of responsibility (Mehus et al. 2004), but it is not possible to conclude whether this is an effect of the transfer.

4.2 Guidelines and standards for a moisture safe building process

In Sweden, a voluntary building industry standard for a moisture-safe building process (ByggaF) was developed (Mjörnell et al. 2012; Fuktcentrum 2013). The standard describes which actions are to be taken by the different actors in a building process from planning to operation. It includes a number of tools and aids for developers to specify requirements for moisture safety early in the project, and to follow up and document the measures employed by different participants. A moisture specialist is mentioned in ByggaF but not in SBR. Instead the industrial partners behind the standard have developed a voluntary moisture specialist education. In Denmark, postgraduate education in building physics was established with reference to DBR's introduction of moisture specialists. However, the authorities have no plans for setting any formal requirements for moisture specialists.

Tools to help the client and the consulting engineer to evaluate what kind of risk is involved when using different solutions or strategies are included both in the Danish guideline (Møller 2010) and ByggaF. The Danish guideline applies humidity risk classes (Tables 1 and 2) to grade the number of actions to be taken to handle moisture in the building process, while ByggaF includes 20 statements that can affect the moisture safety if they are present or might occur, e.g. that moisture-sensitive materials are expected to be used or that the project lacks a moisture specialist. Each of the statements are rated from 1 (not probable) to 5 (highly probable). The average value of these ratings expresses the complexity of the project, but no specific actions are attached to a certain average rating.

Neither ByggaF nor the Danish guideline is referred to in the national building regulations, but ByggaF is based on cooperation between many partners from the Swedish building industry, universities and authorities thus forming a basis for acceptance of the method, while the Danish guideline was initiated solely by the authorities, although a number of partners from the Danish building industry have contributed to the guideline with rules of thumb. The use of the ByggaF method has led to more focus on the importance of moisture safety and is considered to improve the quality of building projects, although the tools and checklists could be simpler to use (Mjörnell et al. 2012). It might be questioned whether the strategy used in Denmark for developing a guideline is suitable for ensuring implementation in the building industry as documentation of the moisture conditions at moving in is almost never present in the documents sent to the authorities as part of the case (de Place Hansen & Aagaard 2013).

Both the Danish guideline and the Swedish standard place the decisions on the client, concerning what kind of activities to launch to prevent moisture from causing damage, as it is in his interest that the building contains no potential defects. It is also highlighted that moisture safety requirements should be incorporated in the planning and project design by integrating moisture prevention in the quality assurance system of the professionals. As the client is usually the person involved in the building process with the least knowledge of technical aspects both Møller (2010) and Fuktcentrum (2013) highlights the need to involve a moisture specialist – or at least consider to involve such a person helping the client to set up and follow up on the requirements regarding moisture safety.

In Norway the need to focus on the relationship between organising the building process and the prevalence of moisture-related building defects in the completed building, and to develop multidisciplinary organisational guidelines on how to deal with moisture problems during planning, design and execution was addressed as well (Lisø et al. 2005; Øyen et al. 2008). Although such guidelines remain to be developed, NBR refers to a number of building detail sheets, including (SINTEF Byggforsk 1998), which contain control items with special focus on moisture protection during project design and execution.

4.3 Disseminating the measures that prevent built-in moisture

The authorities in Denmark, Sweden and Norway have acknowledged that moisture safety needs to be addressed in their building regulations and that guidelines and tools are necessary to help the client to comply with the requirements as they are function-based. Such guidelines and tools can either be mandatory or voluntary. Often the authorities are reluctant to demand that clients follow a specific guideline as this might be regarded as unnecessary costs by the clients. However, measures introduced to improve the quality and reducing the volume of defects in the Danish construction sector have shown that mandatory systems have the greatest impact (de Place Hansen 2013). Moreover, many non-professional clients only build one house in his or her lifetime and do not have the experience gained from previously completed building projects on how to avoid built-in moisture.

As the initiatives implemented in Denmark and Sweden are relatively new, the effect of these remains to be seen but some kind of campaign to make the guidelines known in the building sector could be beneficial. Only in Denmark are systematic records made of building defects and only for social housing projects (Building Defects Fund 2013). However, these are categorised according to specific building parts and not according to whether they are caused by moisture.

The introduction of guidelines/tools to improve the competences concerning moisture safety, and the introduction of moisture specialist educations highlight the need for persons with such competences.

5. Conclusions

The main findings of this study were:

- Function-based requirements were introduced in Denmark, Sweden and Norway to prevent built-in moisture and highlight the responsibility of the client. In Denmark and Sweden, voluntary guidelines and tools operationalise the requirements and describe how to document that the requirements are complied with.
- The guidelines describe how prevention of built-in moisture should be a part of the quality assurance of all partners in the building process.
- Education of moisture specialists introduced both in Sweden and Denmark is vital to ensure that the guidelines and tools become a success by demonstrating how the risk of built-in moisture can be reduced. Only the Danish Building Regulations refer to a moisture specialist
- The effect of the guidelines and tools remains to be seen, but it is questioned whether voluntary guidelines will have the desired effect and whether it is reasonable to exempt specific types of houses from documentation of moisture conditions like in Denmark.

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